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GETTING TO NET-ZERO: CLIMATE CHALLENGES AND SOLUTIONS

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OCTOBER 2021

"The picture's pretty bleak, gentlemen. ... The world's climates are changing, the mammals are taking over, and we all have a brain about the size of a walnut."

www.thefarside.com/

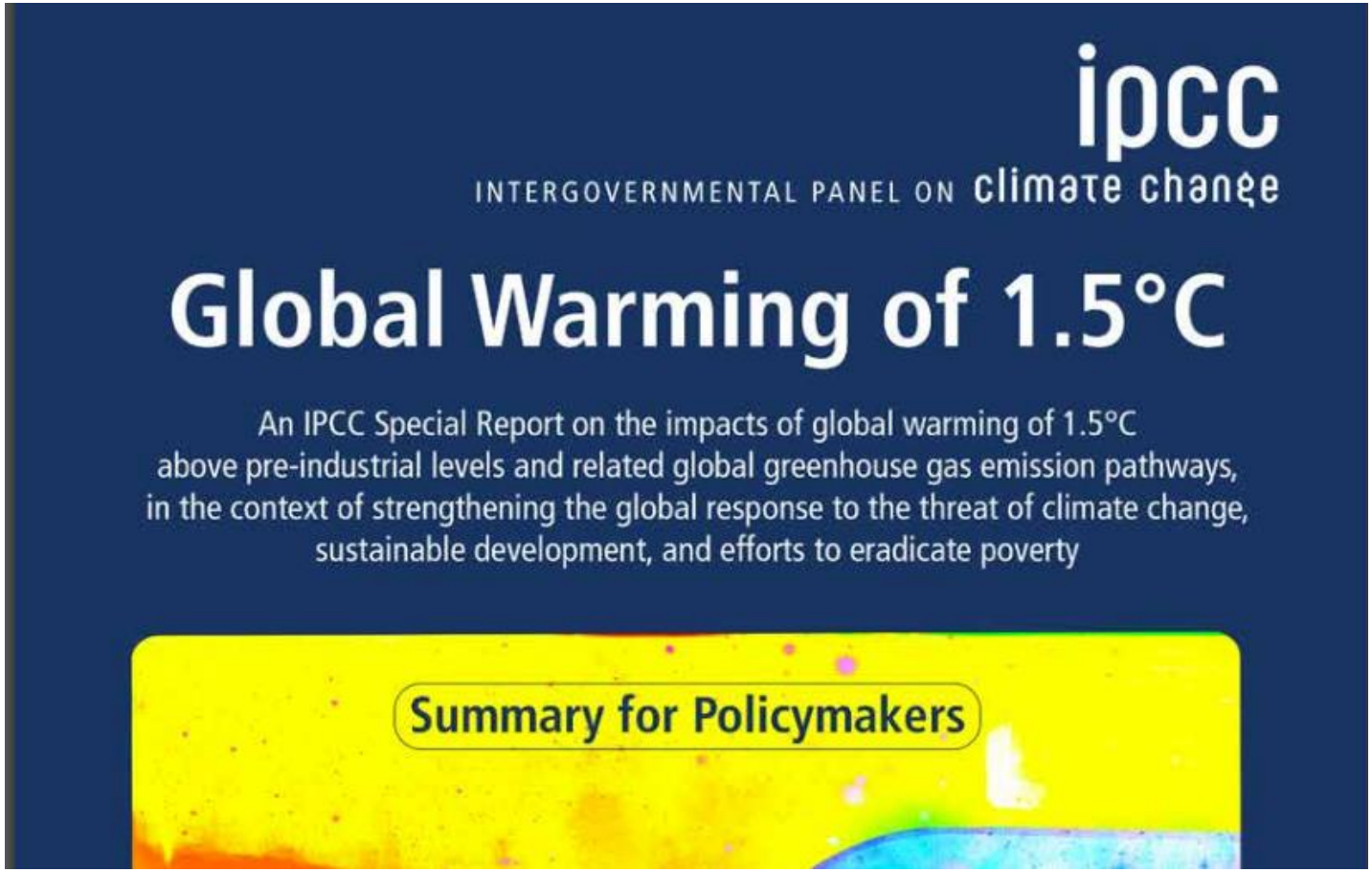
OUTLINE

- The net-zero challenge: the IPCC perspective
- Four key strategies for net-zero
  - Efficiency, electrification,
  - zero-C electricity, carbon capture
- Electricity and the role of renewables
  - Obstacles to 100% renewables
  - A dissenting view
- Carbon capture: the imperative
  - A dissenting view
- The need to “spread our chips” Vegas-style
- Key messages

See weblinks throughout

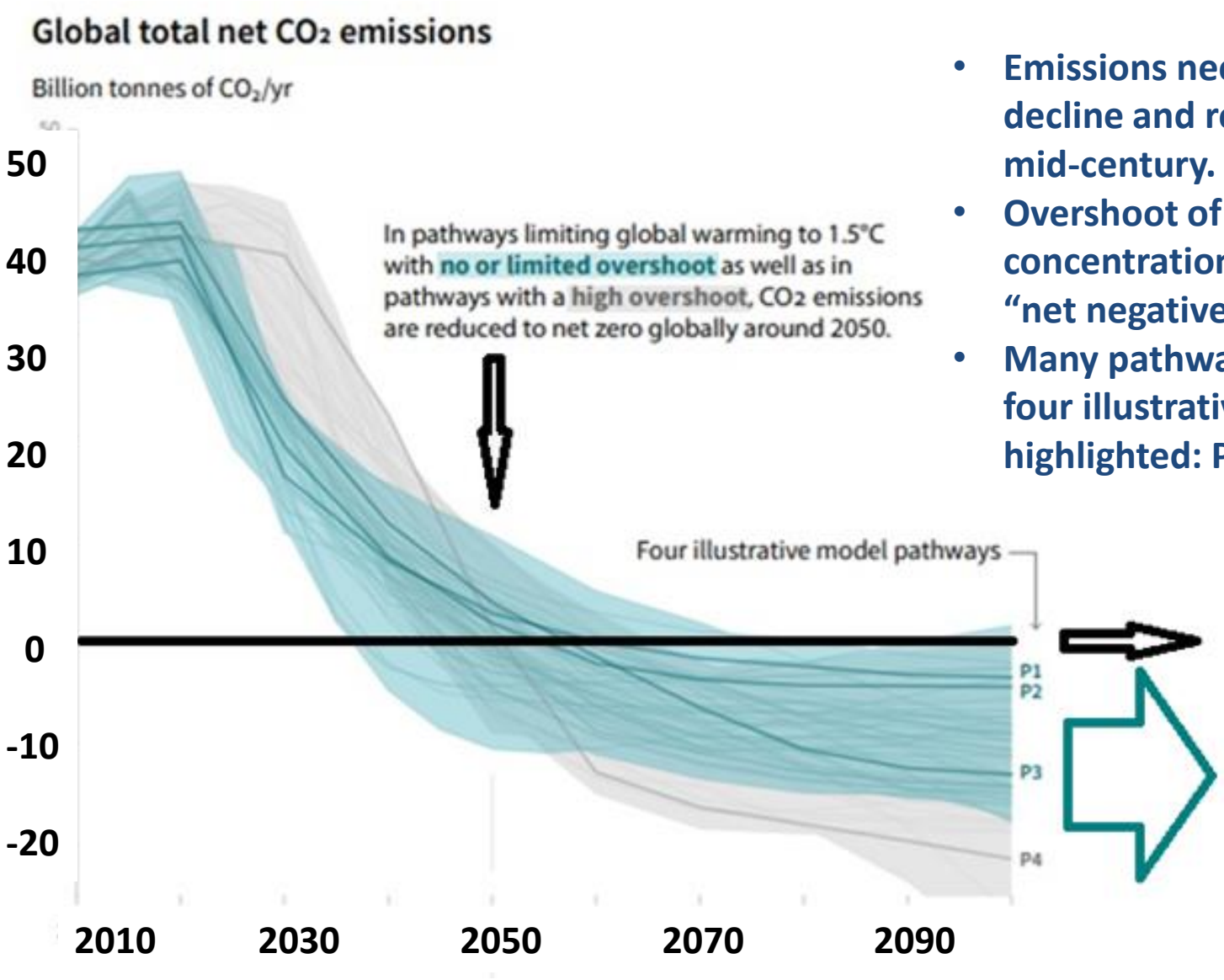
IPCC REPORT RELEASED IN OCT. 2018 LAYS OUT GLOBAL PATHWAYS TO A SAFE CLIMATE

Sixth Assessment Report (AR6): Science report (WG1) released August 2021. Impacts report (WG2) and Mitigation report (WG3) to be released in 2022.



https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

1.5ºC PATHWAYS: GLOBAL EMISSION TRAJECTORIES

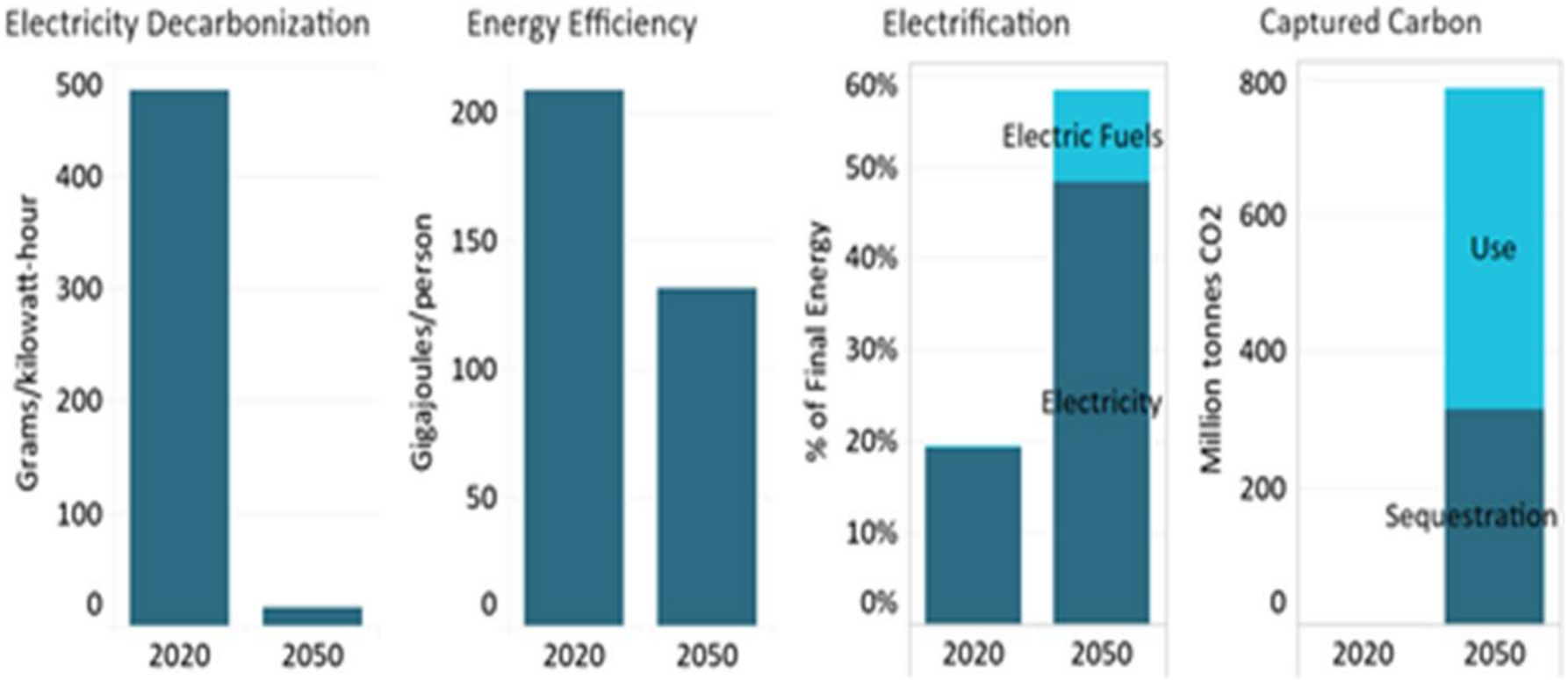


- Emissions need to begin a steep decline and reach net-zero by mid-century.
- Overshoot of safe concentrations is likely, so "net negative emissions needed.
- Many pathways examined and four illustrative pathways highlighted: P1, P2, P3, P4

https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

FOUR KEY STRATEGIES

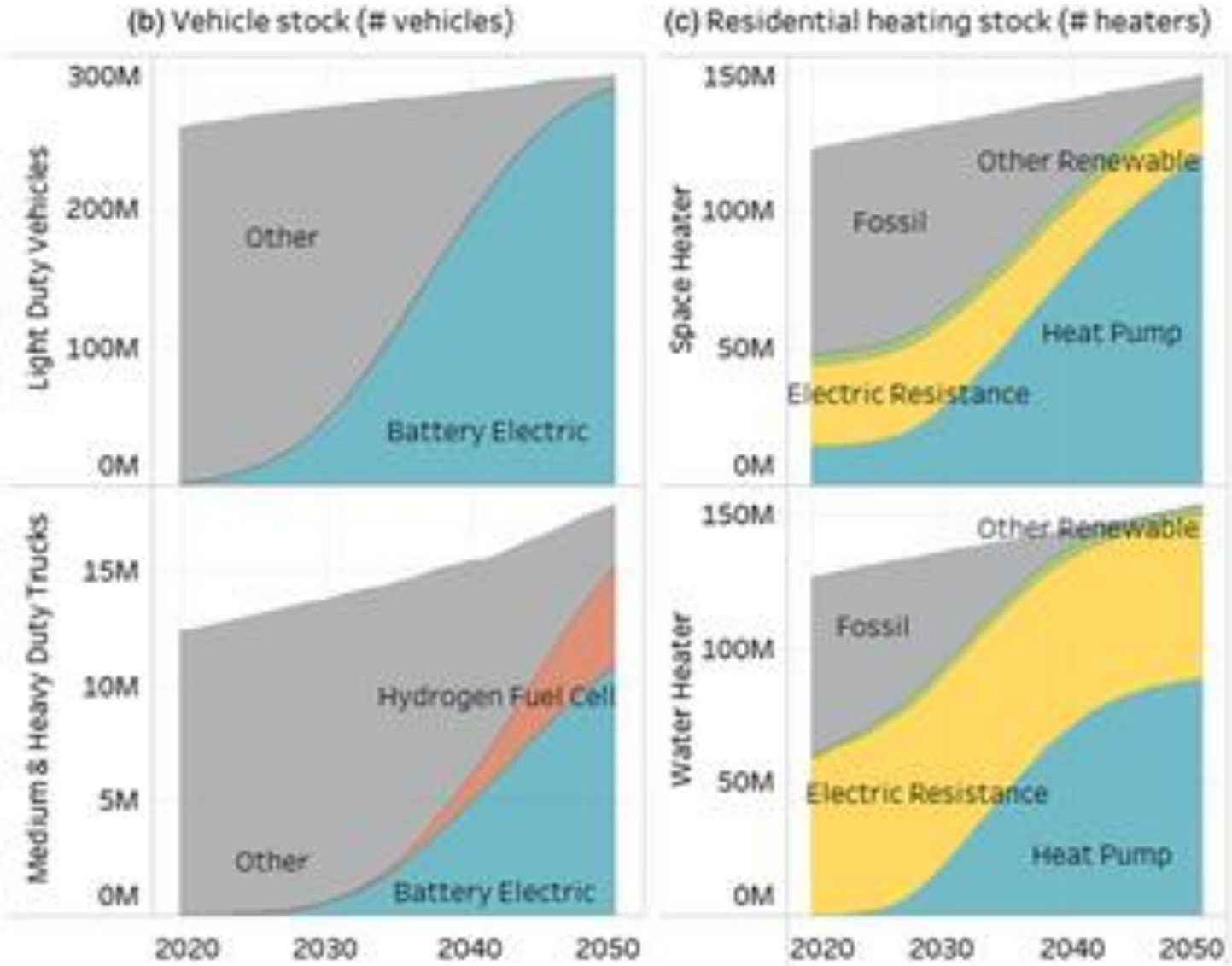
- **Consistent across net-zero pathway modeling**
  - **IPCC, IEA, IRENA, E3, Princeton *Net-Zero America***
  - **Example: Jim Williams et al, *Carbon Neutral Pathways for the US***



IEA, *Net Zero Roadmap*, 2021. IRENA, *Global energy transformation: The REmap transition pathway*, 2019.
E3, various publications: https://www.ethree.com/publication/ https://netzeroamerica.princeton.edu

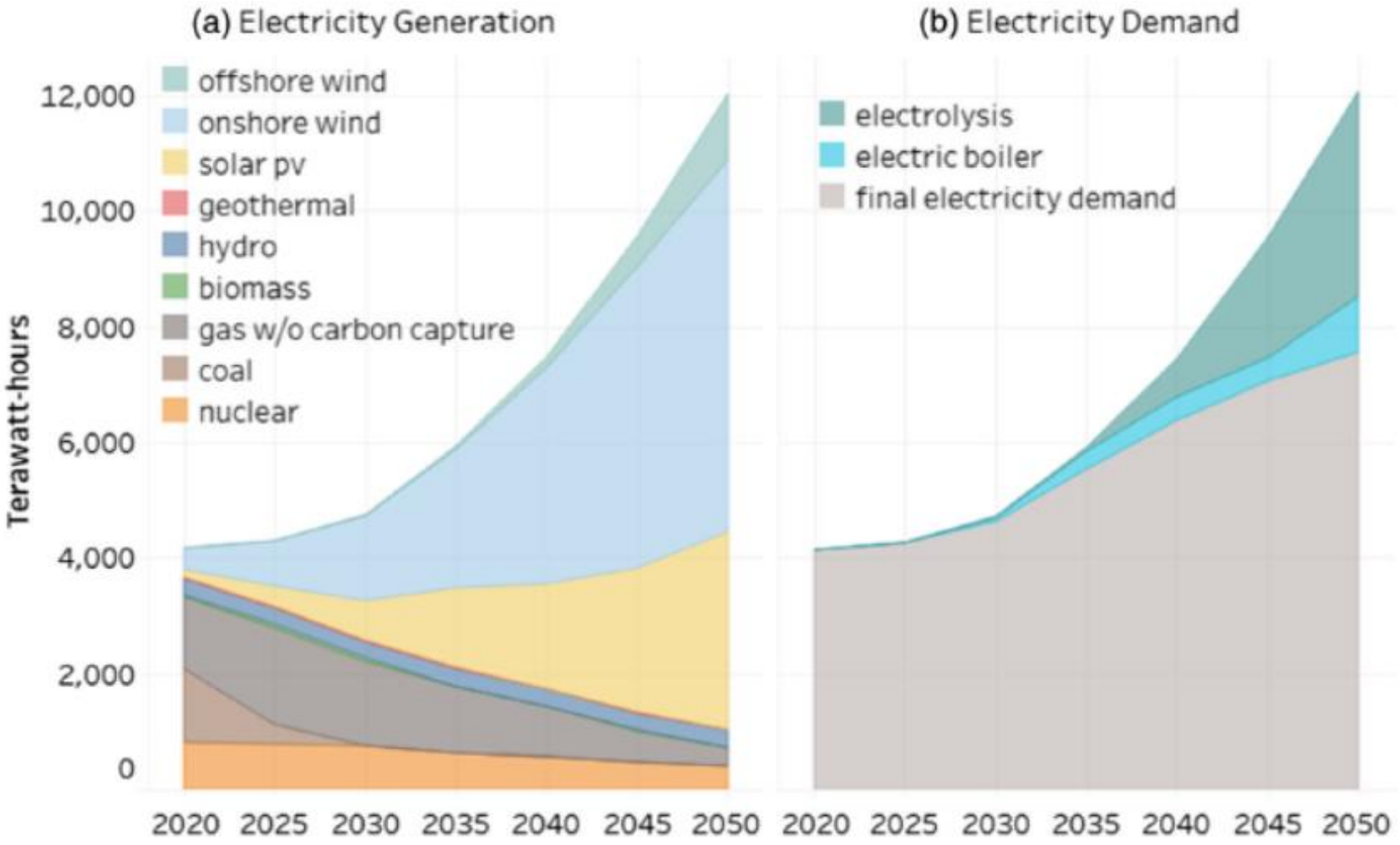
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020AV000284

ELECTRIFYING VEHICLES AND BUILDINGS



https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020AV000284

ELECTRICITY GENERATION AND DEMAND

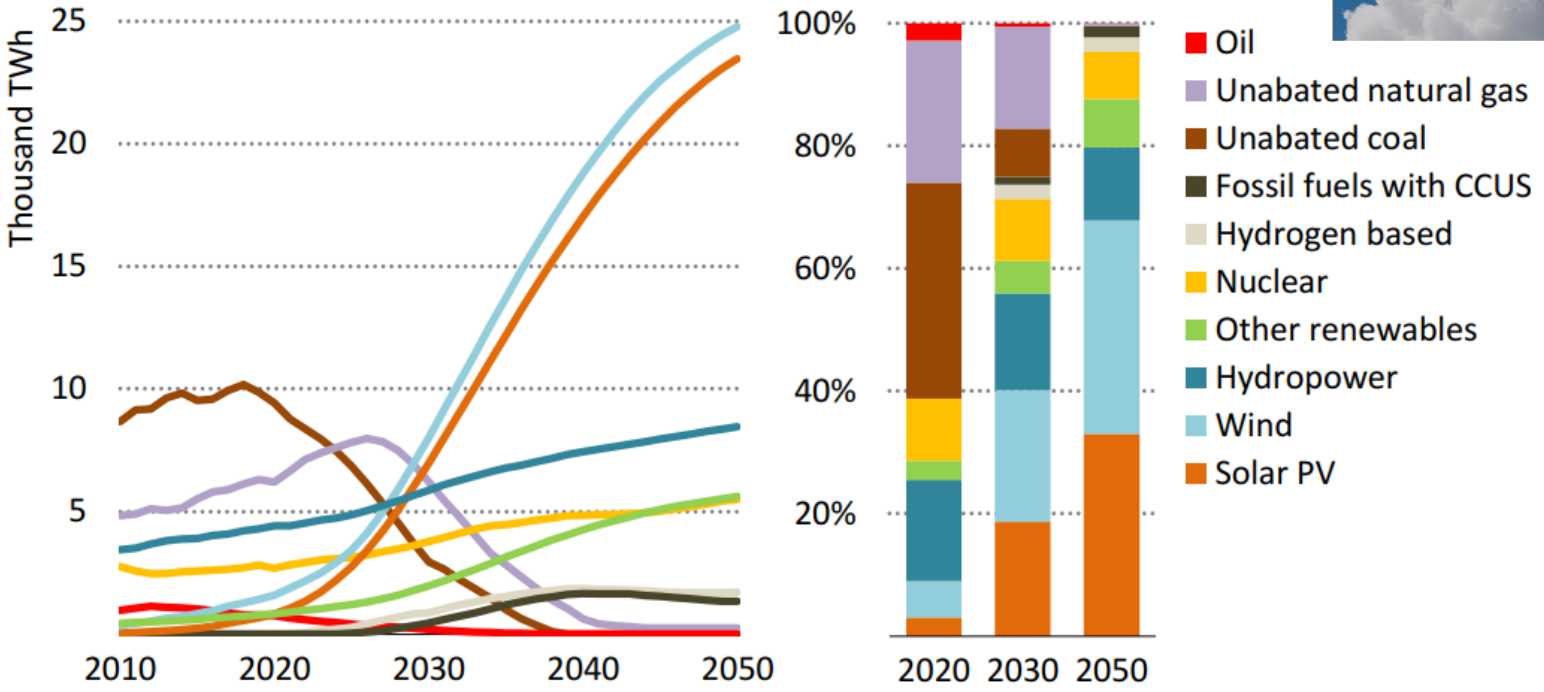


Total generation triples. Wind and solar (>90%) are complemented by "clean firm": hydro, bioenergy, nuclear, gas

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020AV000284

IEA: *NET ZERO BY 2050* (2021)

Figure 3.10 ▷ Global electricity generation by source in the NZE



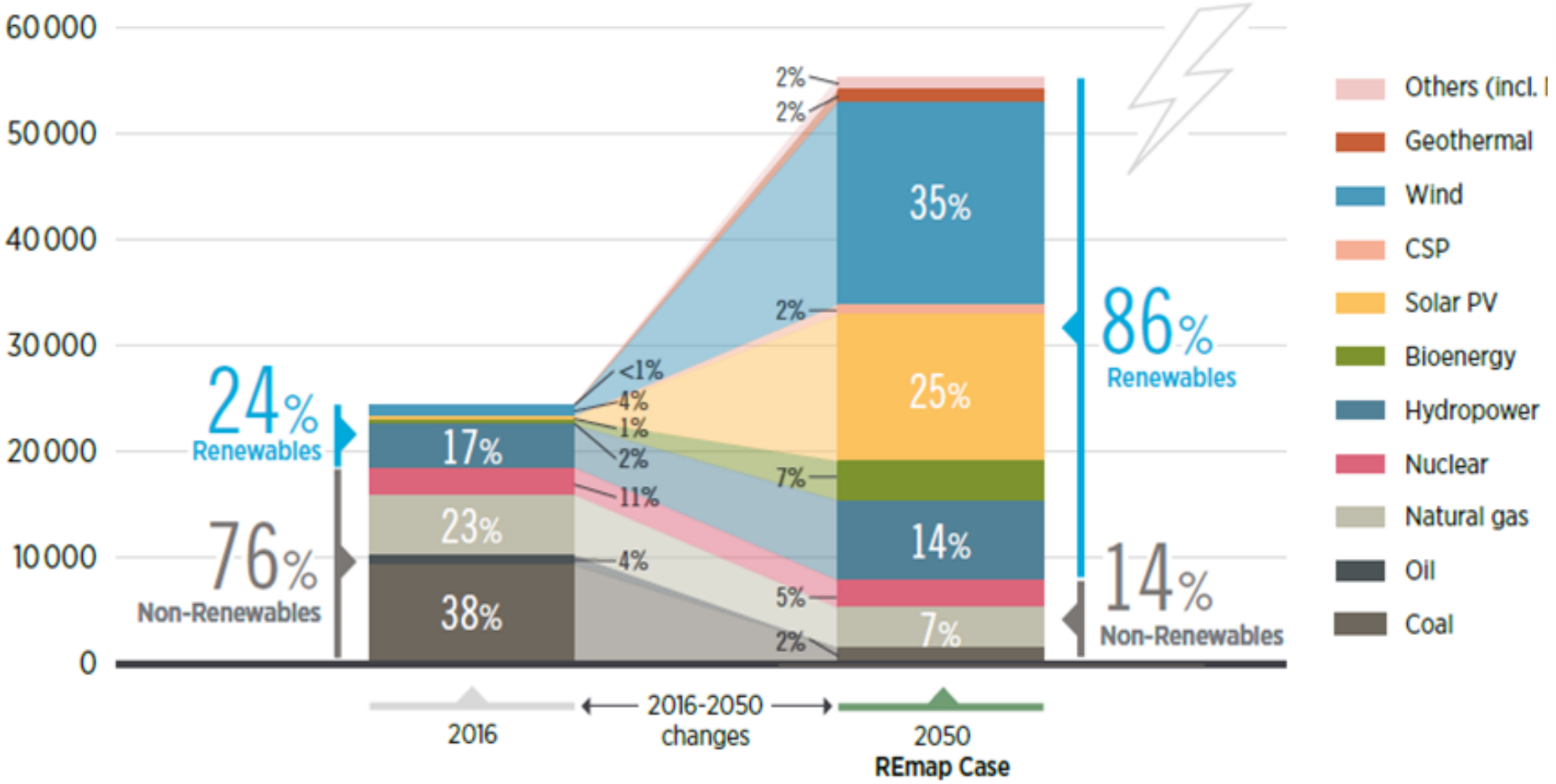
Solar and wind power race ahead, raising the share of renewables in total generation from 29% in 2020 to nearly 90% in 2050, complemented by nuclear, hydrogen and CCUS

Total generation nearly triples. Wind and solar are 68% of generation mix.

https://www.iea.org/reports/net-zero-by-2050

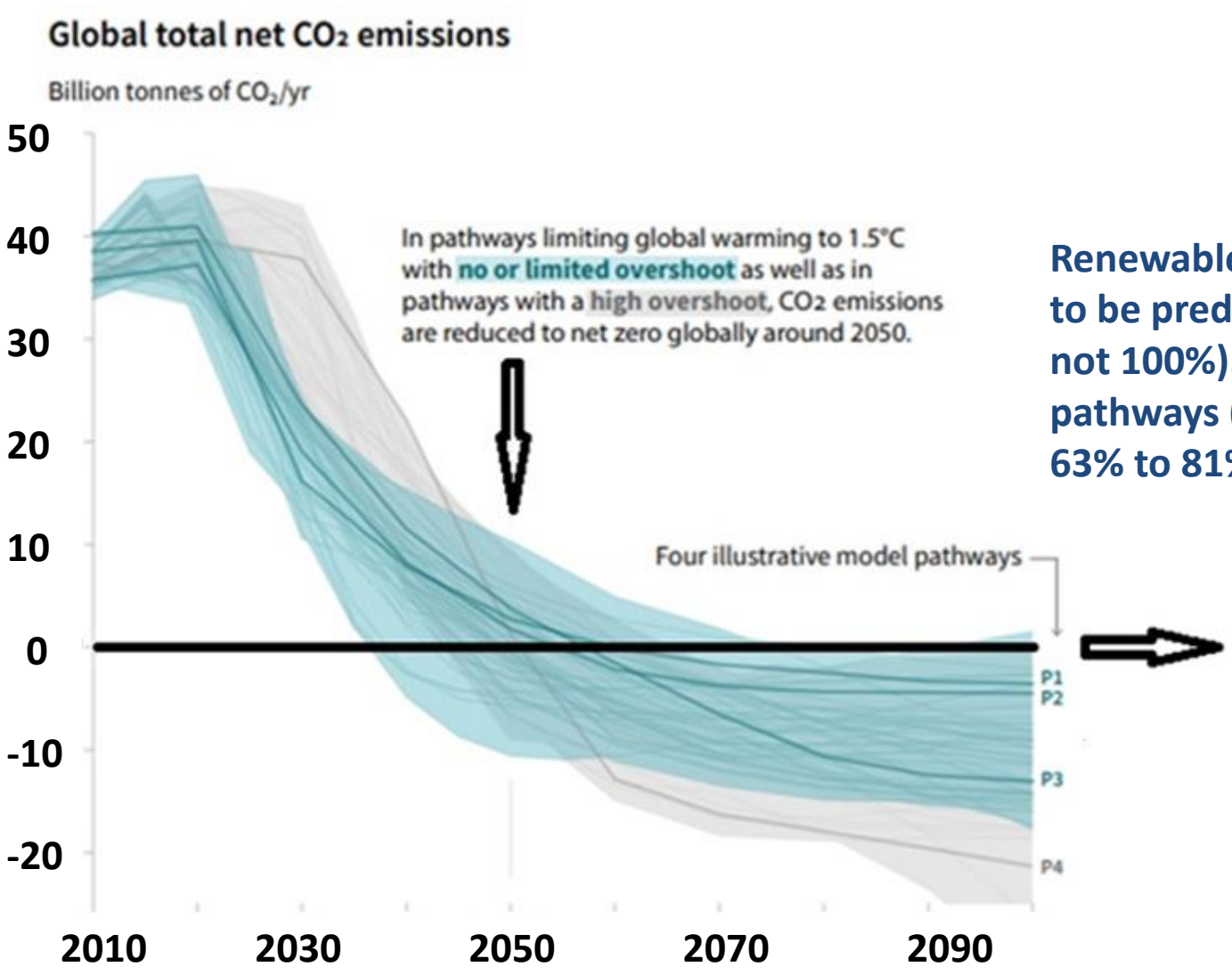
IRENA: *A ROADMAP TO 2050* (2019)

Total generation more than doubles triples. Wind and solar are 60% of generation mix, complemented by hydro, bioenergy, nuclear, gas



https://www.irena.org/publications/2019/Apr/Global-energy-transformation-The-REmap-transition-pathway Fig. 16, p. 38

IPCC 1.5ºC PATHWAYS: ROLE OF RENEWABLES

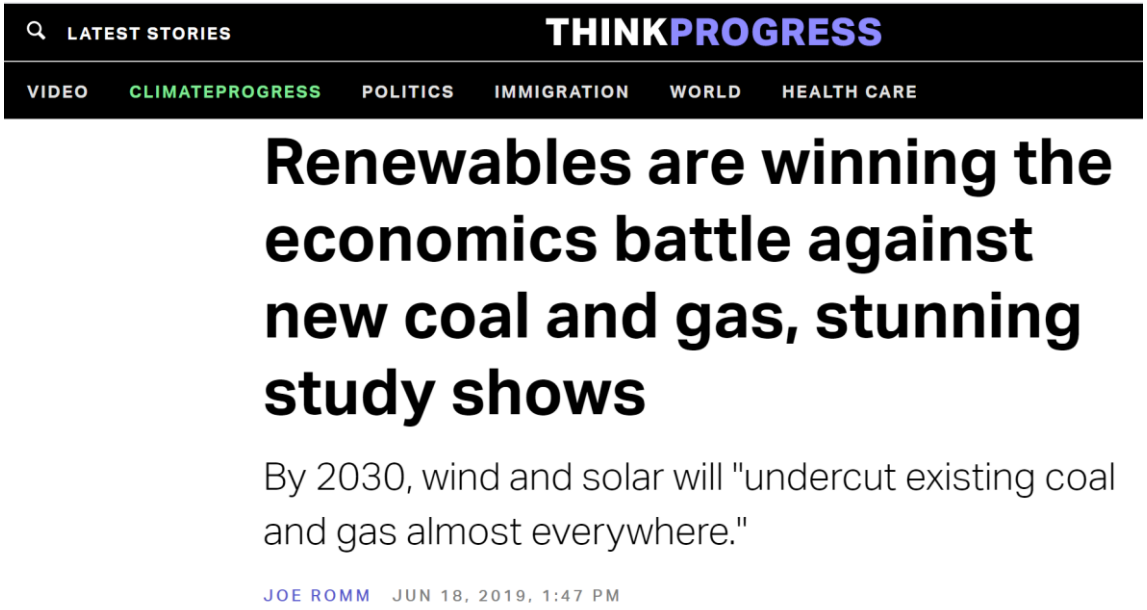


Renewable electricity can grow to be predominant source (but not 100%). Four illustrative pathways (P1-P4) have range of 63% to 81% wind and solar.

Net Zero Emissions

https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

BUT WAIT – AREN'T RENEWABLES NOW THE CHEAPEST SOURCE OF ELECTRICITY?



LATEST STORIES

THINKPROGRESS

VIDEO CLIMATEPROGRESS POLITICS IMMIGRATION WORLD HEALTH CARE

Renewables are winning the economics battle against new coal and gas, stunning study shows

By 2030, wind and solar will "undercut existing coal and gas almost everywhere."

JOE ROMM JUN 18, 2019, 1:47 PM

BUT WAIT – AREN'T RENEWABLES NOW THE CHEAPEST SOURCE OF ELECTRICITY?

LATEST STORIES

THINKPROGRESS

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Renewables are winning the economics battle against

CleanTechnica

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Solar Costs & Wind Costs So Low They're Cheaper Than *Existing* Coal & Nuclear — Lazard LCOE Report

Advertisement

Chester County Solar Installer

BUT WAIT – AREN'T RENEWABLES NOW THE CHEAPEST SOURCE OF ELECTRICITY?

Renewables are winning the economics battle against

SOLAR

WoodMac: Solar Plants Cheaper Than Natural Gas 'Just About Everywhere' by 2023

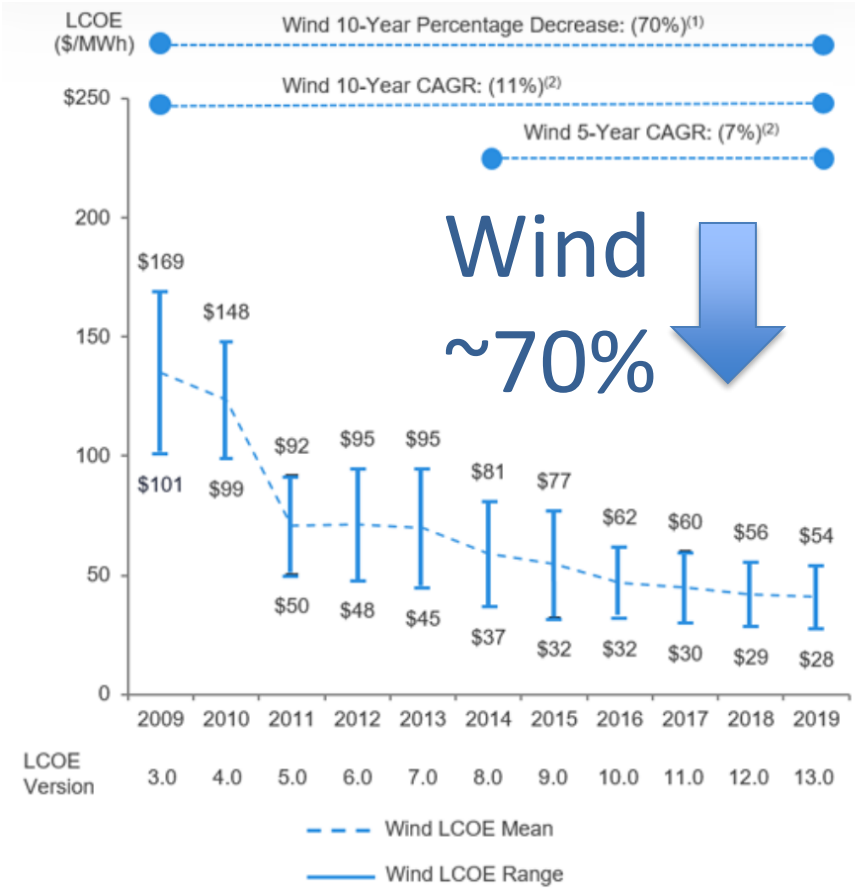
The days of new gas-fired plants keeping up with utility solar on a levelized cost basis may soon be over. But the rise of competitive renewables auctions means profits will be hard to come by, even in an expanding market.

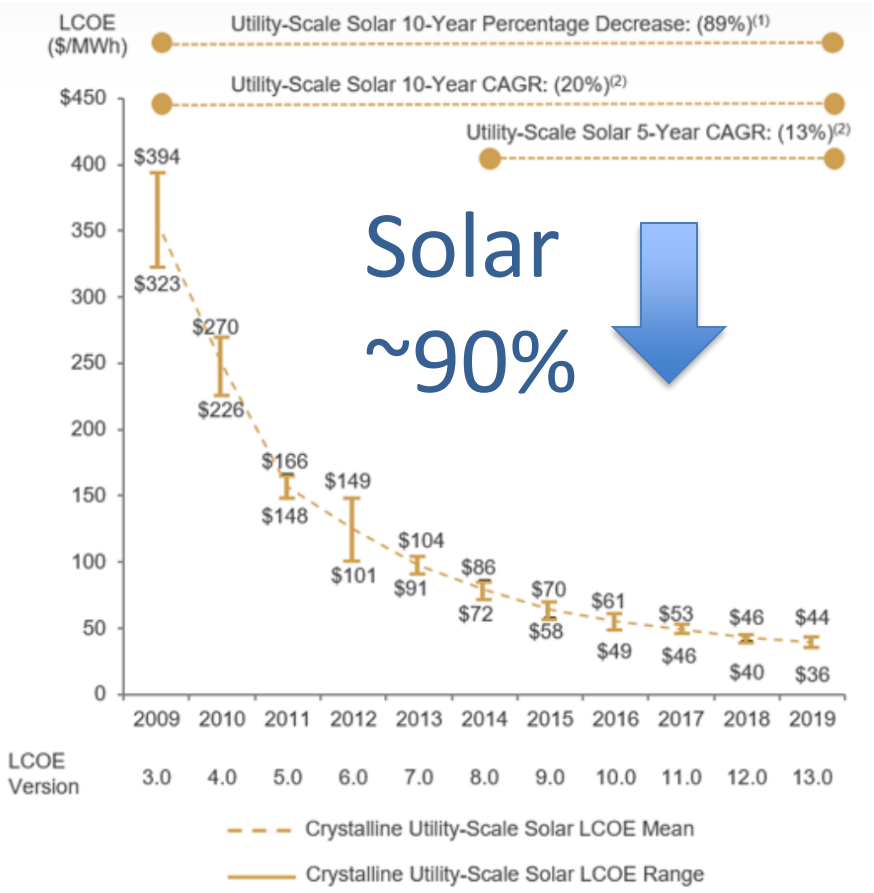
KARL-ERIK STROMSTA | MAY 14, 2019

TUTE

RENEWABLES REVOLUTION ("LCOE" ANALYSIS)

"Levelized Cost of Energy" = average cost of a MWh from a standalone plant
Dramatic cost decreases in wind and solar PV over the past 10 years
Wind: 28 – 54 $/MWh. Utility-Scale Solar PV: 36 – 44 $/MWh.





Lazard's LCOE Analysis, v.13.0, Nov. 2019,
https://www.lazard.com/perspective/lcoe2019

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WHY NOT 100% RENEWABLE?

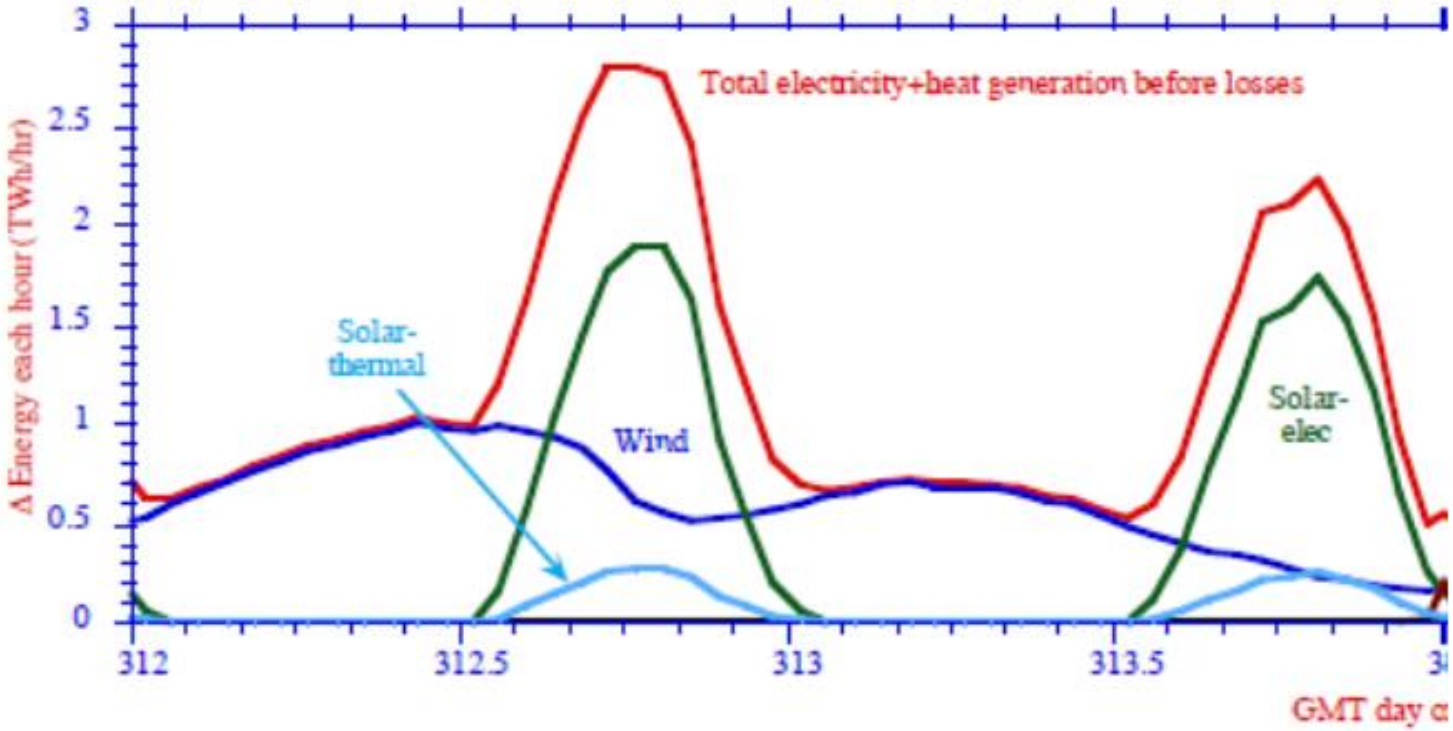
MAYORS FOR 100% CLEAN ENERGY
#Mayors4CleanEnergy

GO 100% RENEWABLE ENERGY

The riddle of “cheap” renewables” and high total system costs...
Mainstream modelers project that as a power system moves closer and closer to 100% solar and wind, at some point the total system costs increase sharply.
Need a quick deep dive…

SOLAR AND WIND ARE VARIABLE - DAILY

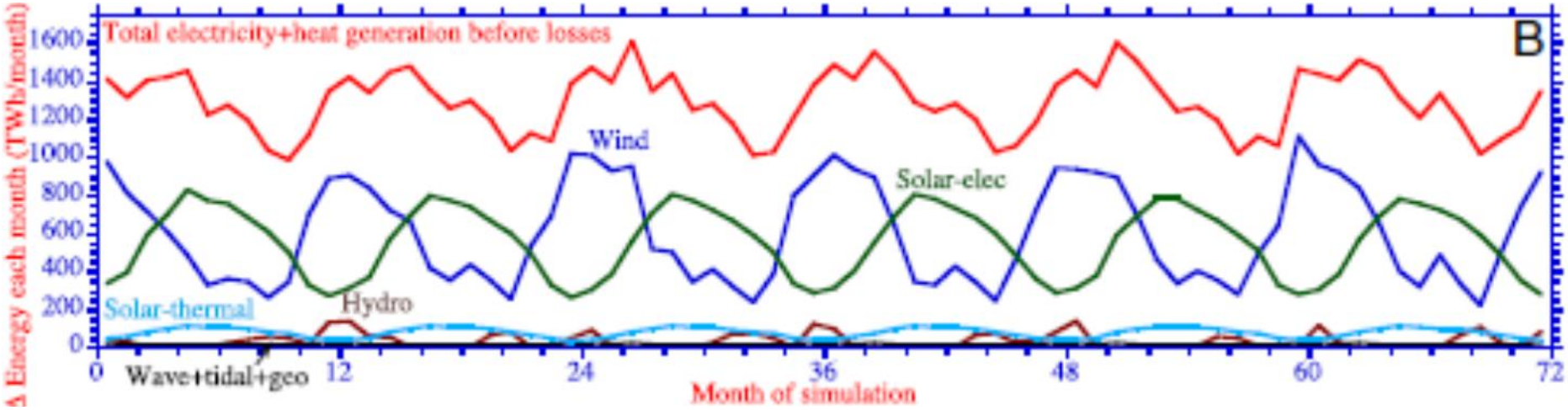
- Solar and wind are variable in their output. They are not "firm" like most traditional generation. They cannot be "dispatched" to follow load.
- Daily variation depicted in modeling by Jacobson (48 hours)
  - Solar (green) is available roughly half the day, except during cloud cover
  - Wind (blue) is more random in output, but can be available for 24 hours
  - This modeling assumes aggregation over entire US



https://www.pnas.org/content/112/49/15060/tab-figures-data

SOLAR AND WIND ARE VARIABLE - SEASONAL

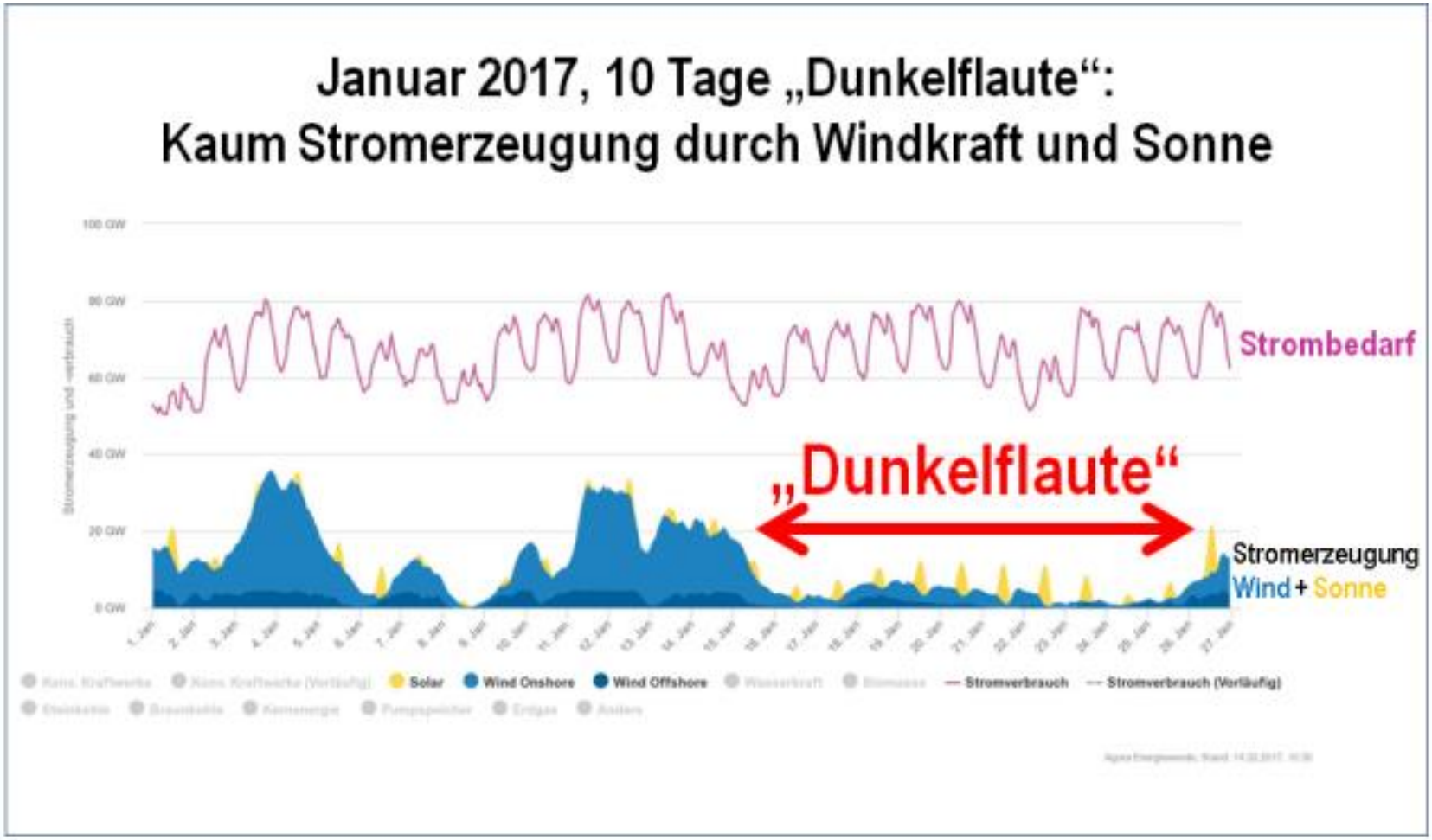
- Monthly variation depicted in modeling by Jacobson (72 months)
  - Solar output varies by factor of ~2 over different seasons (highest in summer, lowest in winter)
  - Wind output varies even more (highest in spring, lowest in fall)
  - Total solar and wind **(red)** varies by 50% by season (lowest in fall/winter)
  - (Figure includes small amount of solar thermal and hydro)



https://www.pnas.org/content/112/49/15060/tab-figures-data

SOLAR AND WIND AND VARIABLE – RANDOMLY

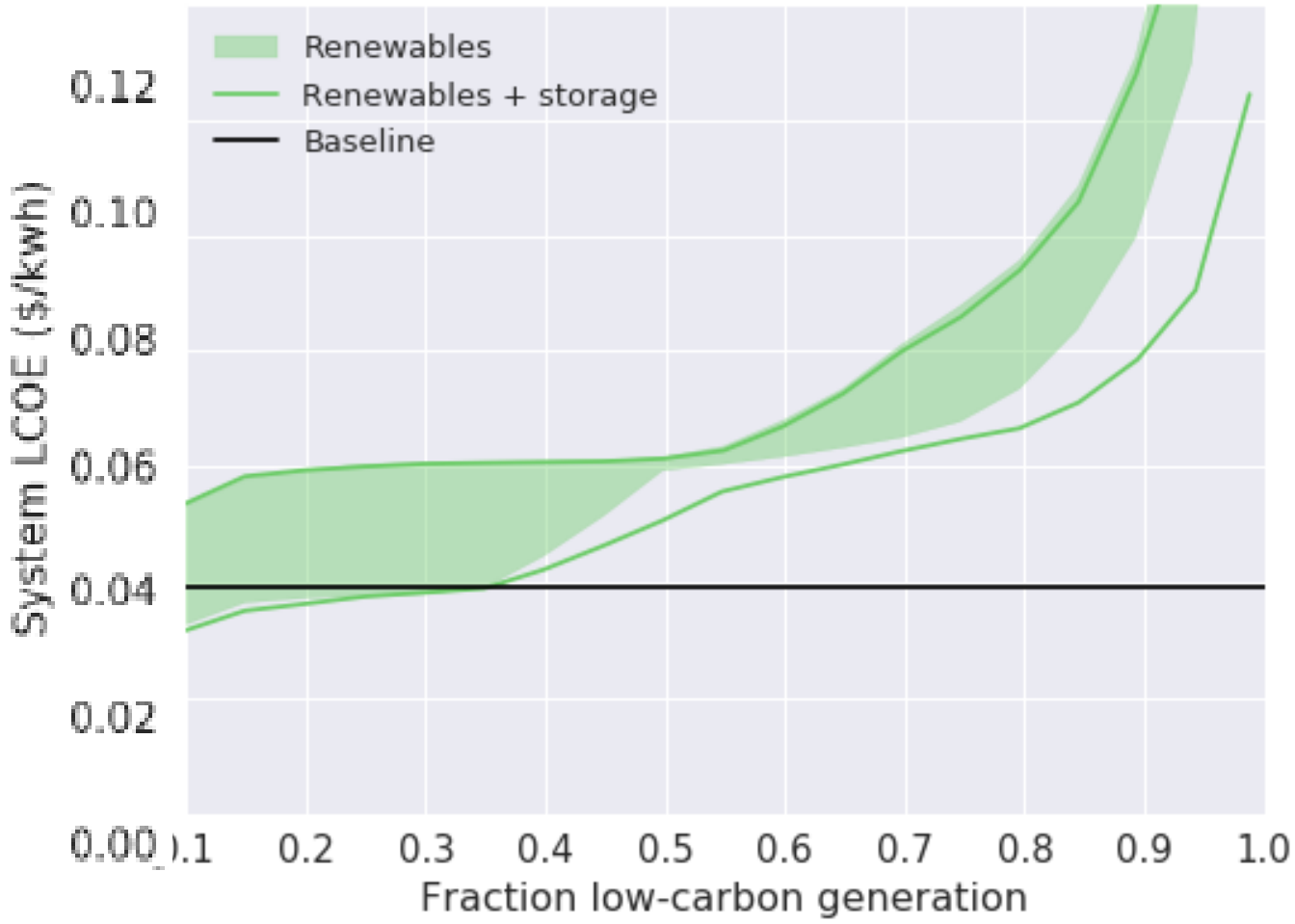
THE GERMANS HAVE A WORD FOR THAT: "DUNKELFLAUTE" (DARK DOLDRUMS)



https://deepresource.wordpress.com/2019/11/03/heat-storage-as-key-to-seasonal-energy-storage/
This article proposes seasonal thermal storage to help overcome dunkelflaute

SOLVING THE RIDDLE OF "CHEAP RENEWABLES" AND HIGH SYSTEM COSTS

ILLUSTRATIVE SYSTEM WITH WIND, SOLAR & STORAGE



See also: Hausker (2019), https://kleinmanenergy.upenn.edu/paper/betting-climate-solutions
Frew et al (2016) , https://web.stanford.edu/group/efmh/jacobson/Articles/Others/16-Frew-Energy.pdf
Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule*

Platt, et al (2017) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3015424

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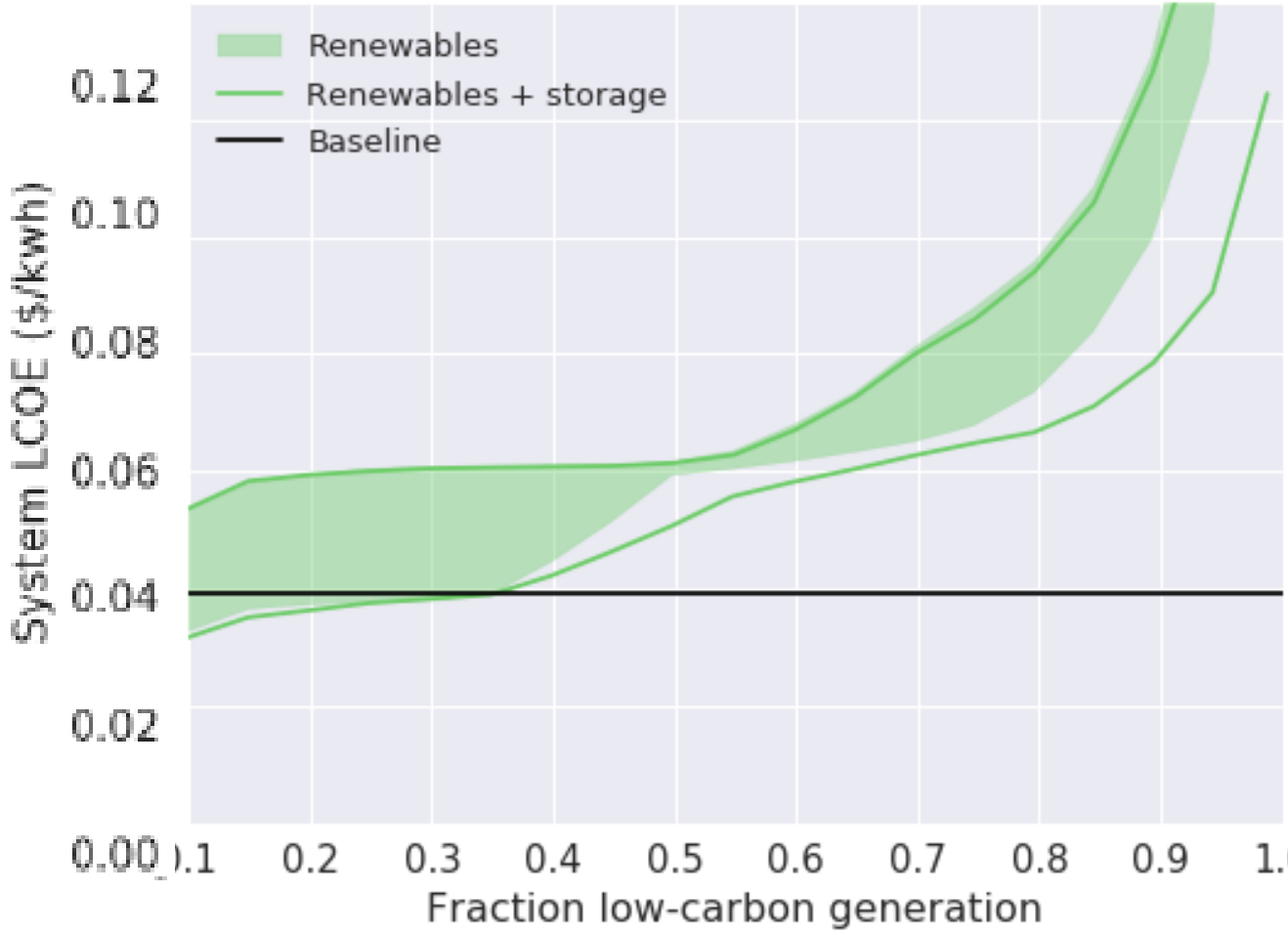

"Integration" costs drive up system LCOE:

1. **Transmission**
2. **Load shifting**
3. **Storage**
   - **Daily**
   - **Seasonal**
   - **Weather flux**
4. **"Overgeneration"**

Spreading large capital costs over infrequent but challenging periods of low RE generation would be very costly

See also: Hausker (2019), https://kleinmanenergy.upenn.edu/paper/betting-climate-solutions
Frew et al (2016) , https://web.stanford.edu/group/efmh/jacobson/Articles/Others/16-Frew-Energy.pdf
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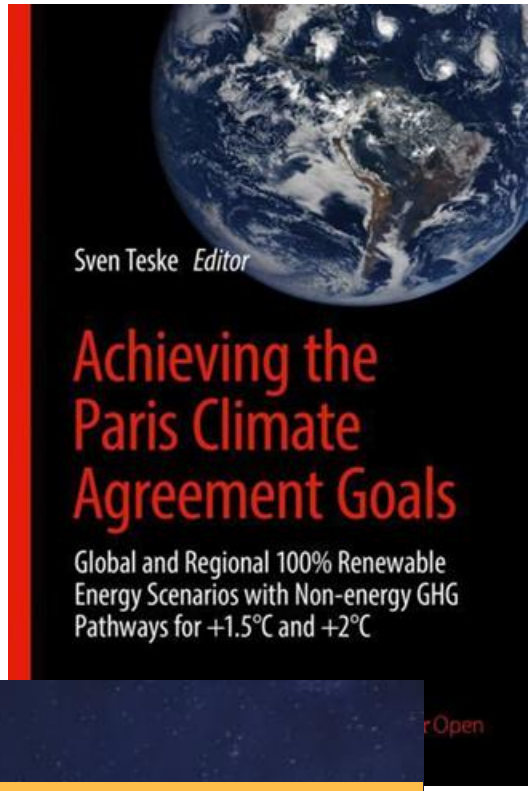
Platt, et al (2017) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3015424

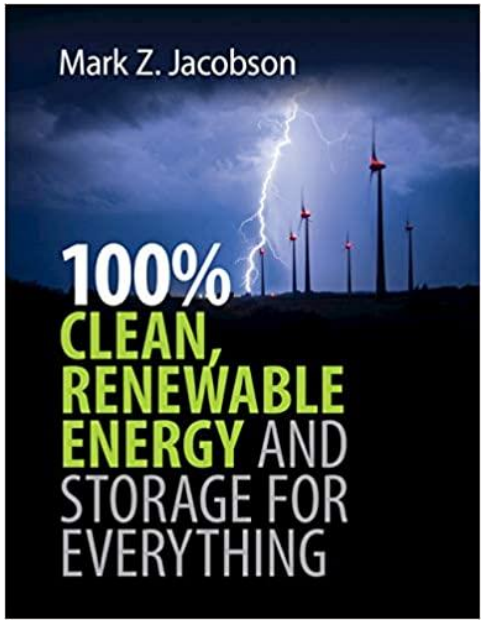
A DISSENTING VIEW…

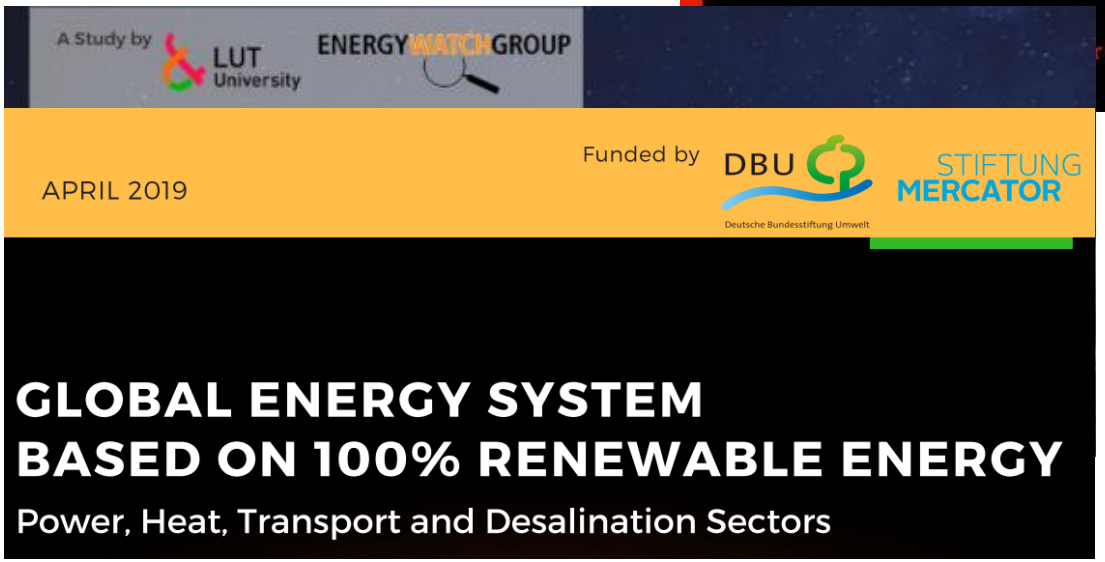
Some modelers rule out certain options (nuclear, carbon capture and storage) and create and advocate for "100% renewable" pathways. Typically they include:

- **Massive expansion of transmission systems**
- **Massive amounts of battery storage and/or thermal storage, load shifting**
- **Hydro, geothermal, hydrogen turbines**

This may be technically feasible…







http://energywatchgroup.org/wp-content/uploads/EWG_LUT_100RE_All_Sectors_Global_Report_2019.pdf

GIVING 16 AUTHORS FROM NREL THE LAST WORD

From: Denholm et al, "The challenges of achieving a 100% renewable electricity system in the United States." *Joule*. 2021

"Economically reducing overall United States GHG emissions will likely involve achieving very high (80% or more)—
but potentially below 100%—RE generation while also focusing on decarbonizing other sectors … or applying non-RE low-carbon resources -- such as CCS --to the electric sector."

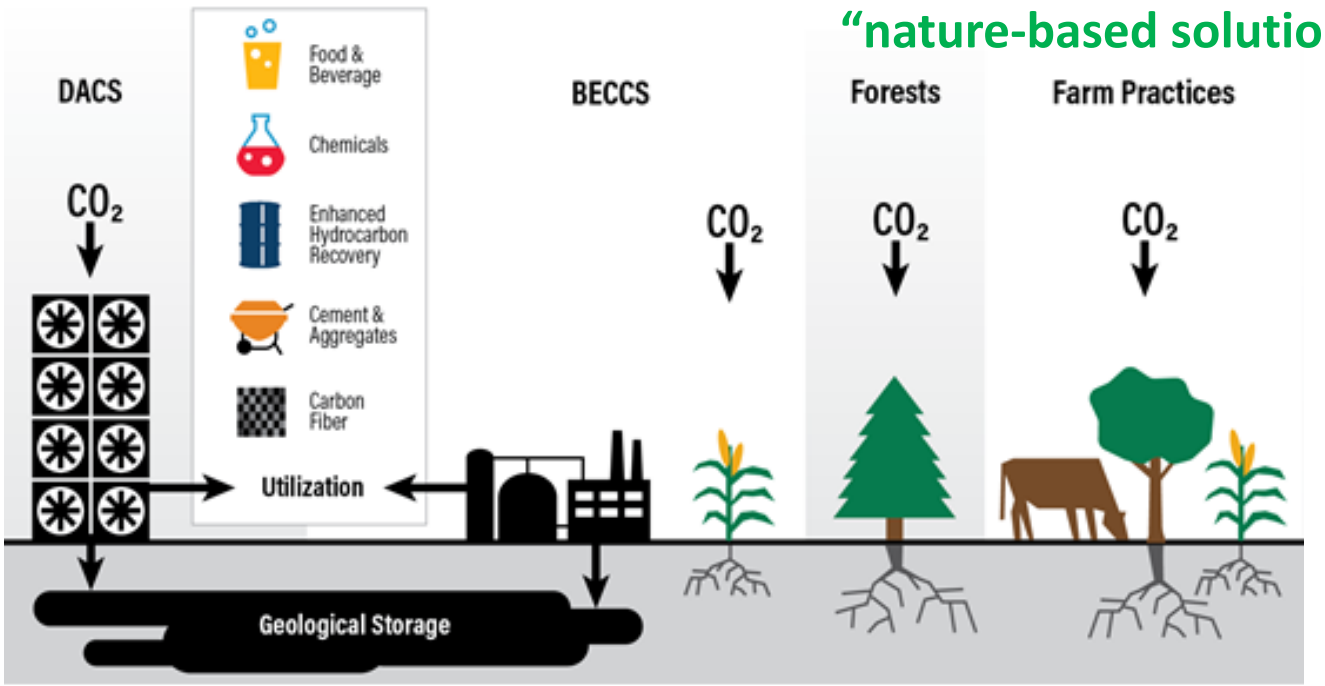
"Reducing the costs of low-carbon generation in the electric sector, potentially by keeping non-RE options (including CCS and nuclear) available, enables electrifying and thus decarbonizing other sectors, reducing economy-wide carbon emissions."

In other words, don't bet ALL your chips on RE…

THE ROLE OF CARBON CAPTURE IN NET-ZERO

Mainstream modeling of net-zero pathways indicates needs for carbon capture and storage (CCS):

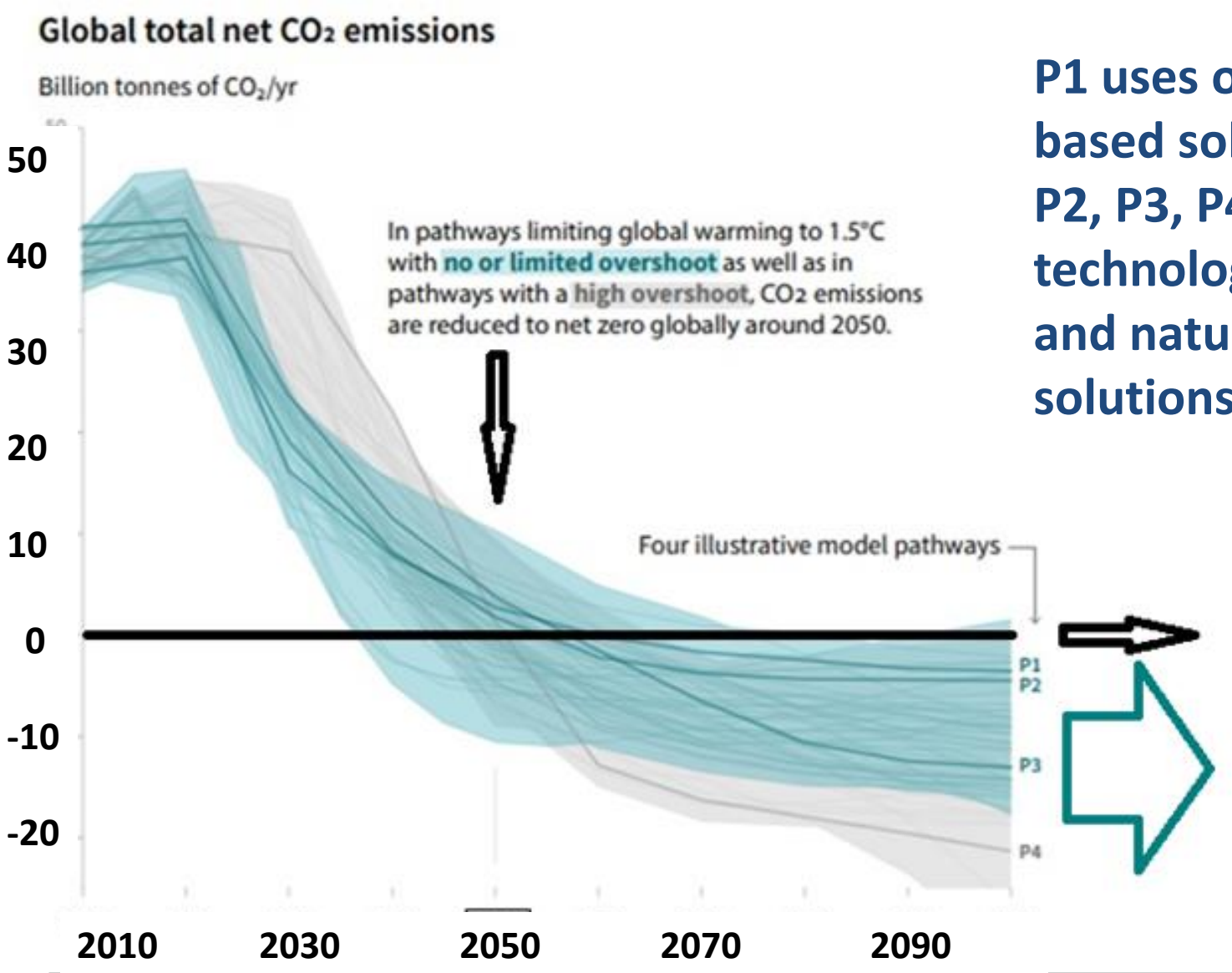
- Reduce emissions from power plants and/or industrial sources
- Carbon dioxide removal from the atmosphere
  - "Technology-based": Direct Air Capture & Storage, Bioenergy with CCS



Also at research stage: Enhanced weathering of rocks/minerals, and seawater capture

https://www.wri.org/publication-series/carbonshot-creating-options-carbon-removal-scale-united-states

THE CARBON CAPTURE IMPERATIVE



P1 uses only nature-based solutions. P2, P3, P4 use technology-based and nature-based solutions.

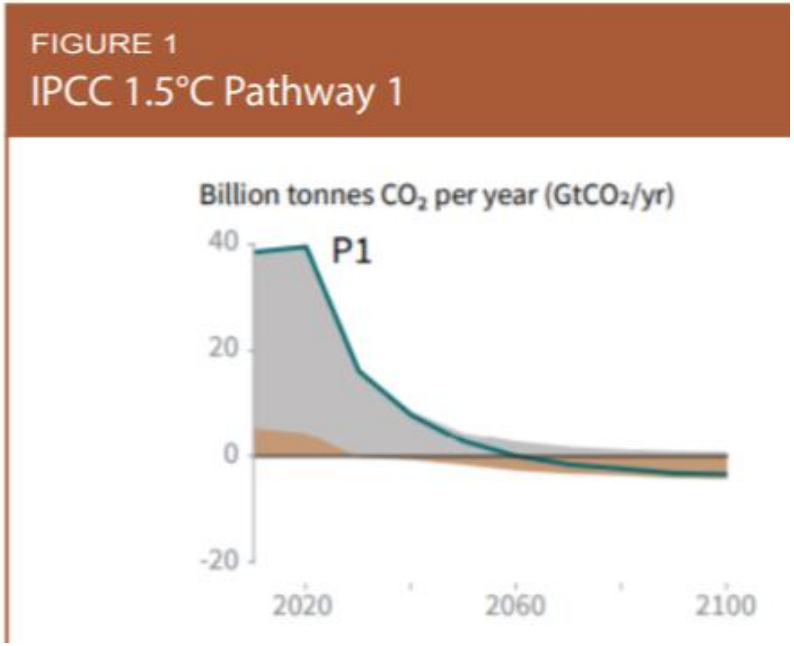
Net Zero Emissions

All pathways require Carbon Dioxide Removal

https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

A DISSENTING VIEW ON CARBON CAPTURE

- ‘doesn’t work’
- ‘too expensive’
- ‘too risky’
- ‘prolongs dependence on fossil fuels’



“The surest approach to avoiding climate catastrophe does not involve CCS. According to the IPCC, the emissions reduction pathway with the best chance of keeping warming at or below 1.5°C makes limited to no use of engineered carbon capture technologies. This pathway involves a rapid phaseout of fossil fuels along with limited carbon removal by natural sources such as reforestation…”

IMPORTANT CAVEAT: P1 requires global energy use to drop by one-third by 2030…

https://www.ciel.org/wp-content/uploads/2021/07/Confronting-the-Myth-of-Carbon-Free-Fossil-Fuels.pdf

BETTING ON CLIMATE SOLUTIONS: SHOULD WE…

Place all our chips on renewables?

Are the risks of nuclear power unacceptable?
Should carbon capture be excluded from our options?
Should we "Leave It in the Ground"?

… Or spread our chips on a broader portfolio?

Fotossearch.com

KEY MESSAGES

- Be extremely efficient
- "Electrify everything"
  - Make hydrogen and other low/zero-carbon fuels to fill niches
- Produce mountains of zero-carbon electricity
  - Build out wind and solar aggressively – integration costs are still low
  - Create viable nuclear, CCS, and other options
  - Expand the transmission system to tap areas rich in wind and solar
- Commercialize carbon capture for CDR, industry, electricity.
  - CCS should become fully commercialized in the 2020s.
  - Capture, pipelines, injection sites, governance, public acceptance
- Spread your chips: need aggressive, well-designed RD&D programs with a broad portfolio
- Global perspectives – food for thought…
  - Building out renewables without legacy fossil plants
  - Nuclear power
  - CCS

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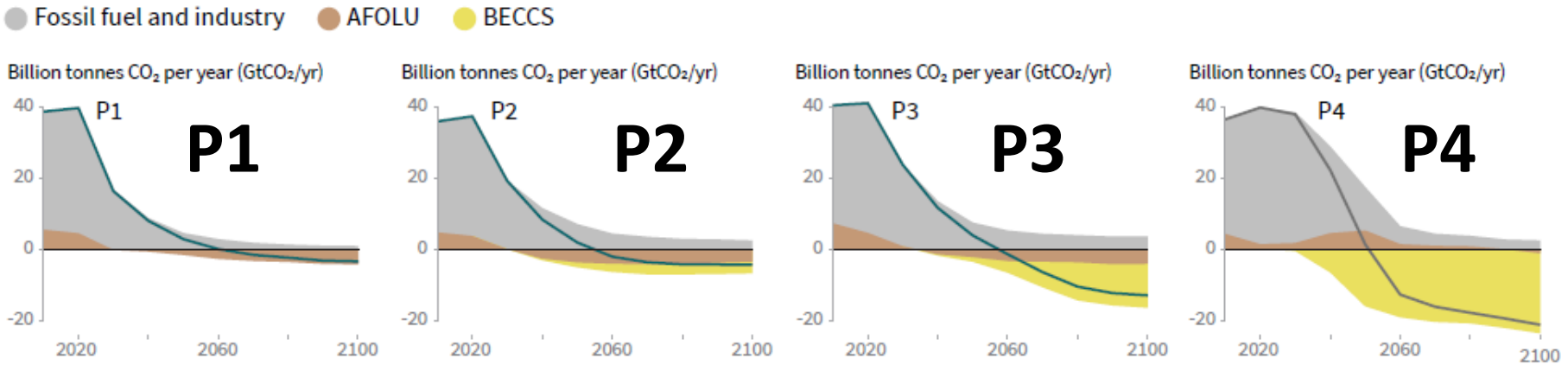
THANK YOU

Karl Hausker, Ph.D.
Senior Fellow
khausker@wri.org

CDR IN THE IPCC PATHWAYS – HOW AND HOW MUCH

- **Carbon dioxide removal (CDR) needed via AFOLU (Agriculture, Forestry, Other Land Use), BECCS (Bioenergy with CCS), and/or other technologies & processes (e.g. DACS (Direct Air Capture and Storage))**
- **P1, P2 and P3: "no or limited overshoot" P4: "high overshoot"**

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

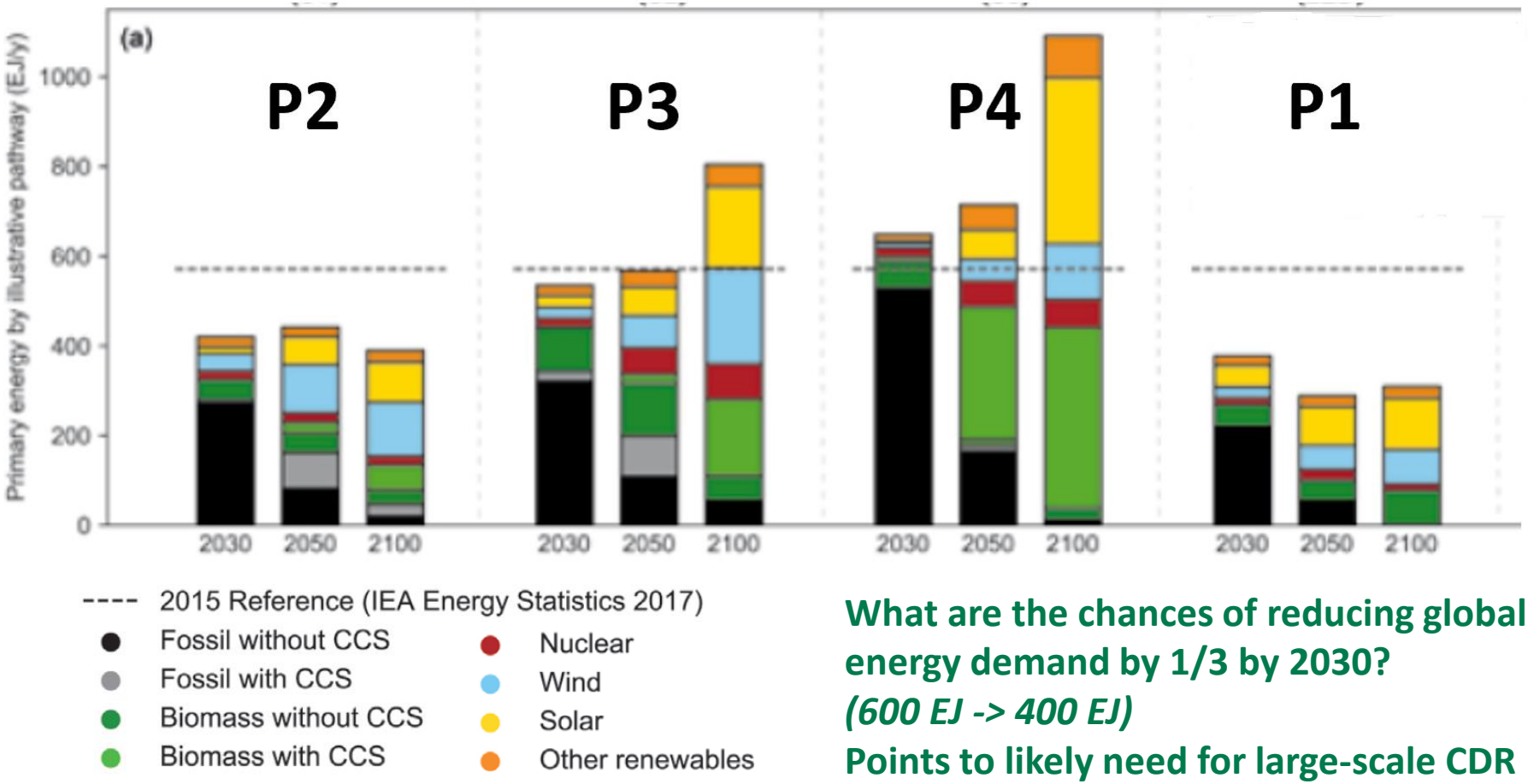
P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf

IPCC FOUR PATHWAYS: PRIMARY ENERGY SUPPLY

Renewables grow exponentially. CCS and nuclear play key roles.
P1 and P2: primary energy decreases from ~600 EJ/yr to ~400 EJ/yr by 2030
P3: slight decrease by 2030; back to ~600 EJ/yr by 2050.
P4: slow growth through 2050



What are the chances of reducing global energy demand by 1/3 by 2030?
(600 EJ -> 400 EJ)
Points to likely need for large-scale CDR

https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf
Fig. 2.15 (legend corrected per Fig. 2.16 and pathway labels added).

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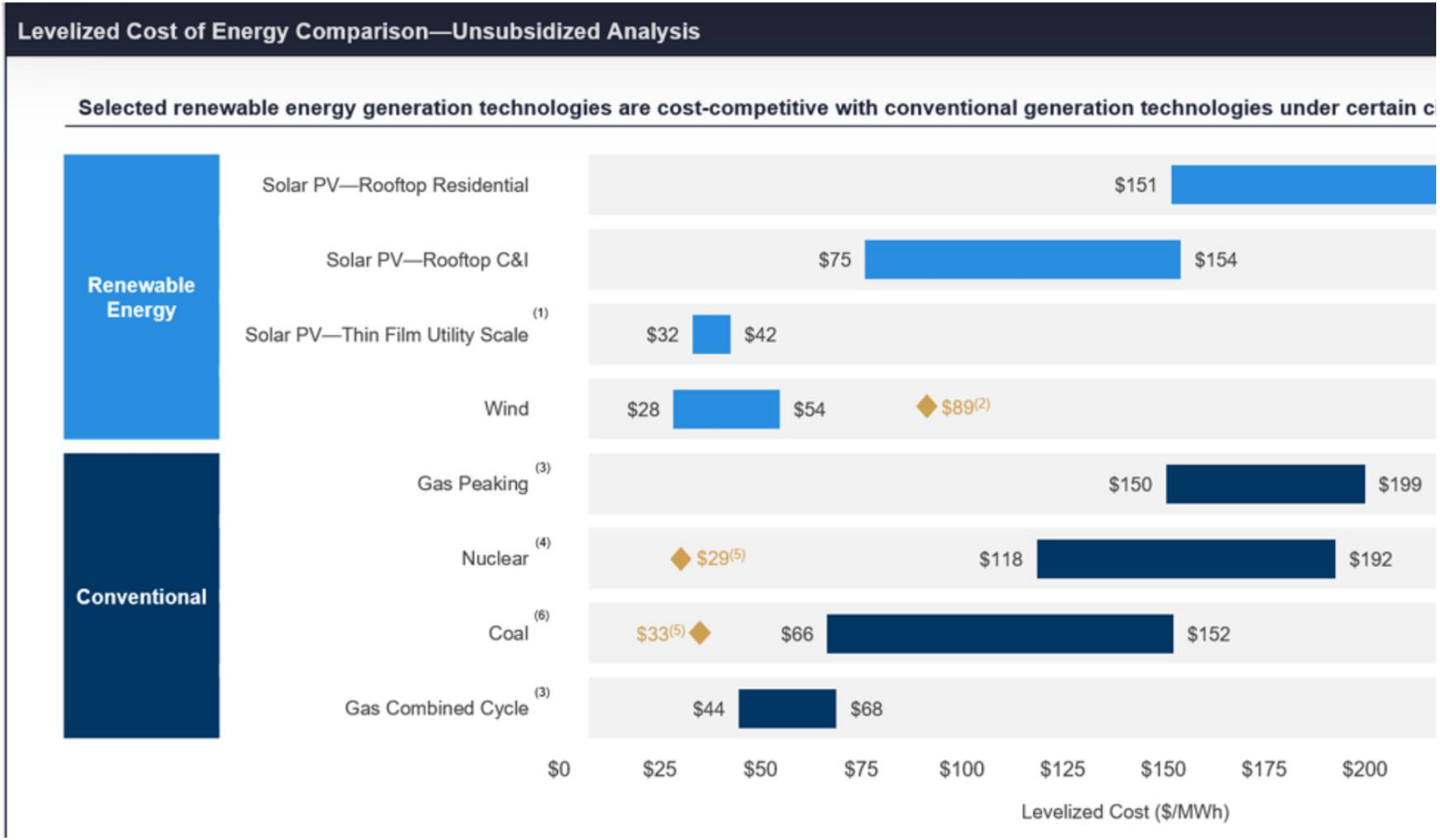
LAZARD COMPARISON OF LCOE



https://www.lazard.com/perspective/lcoe2019

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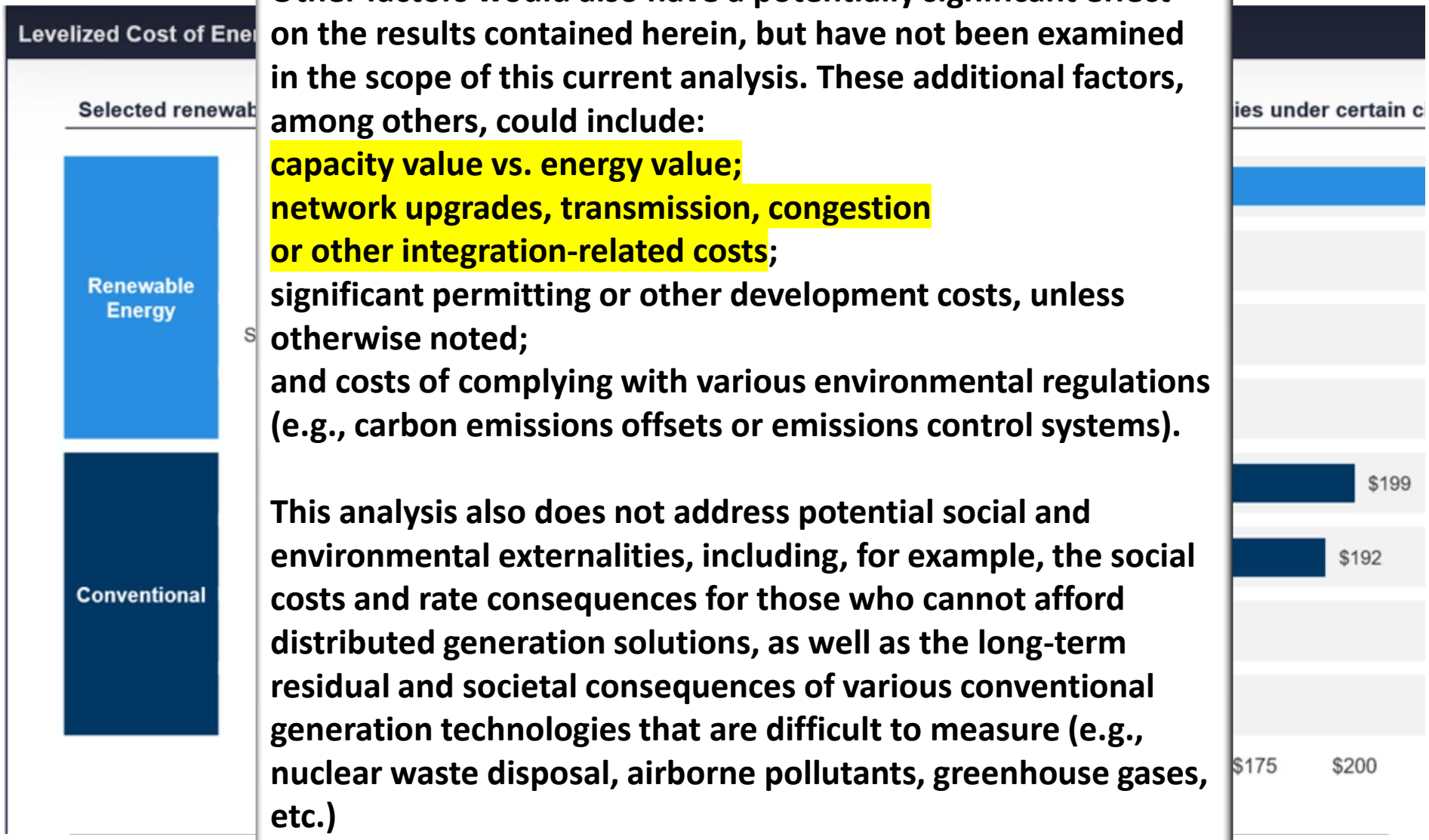
THE "FINE PRINT" IN LCOE ANALYSIS

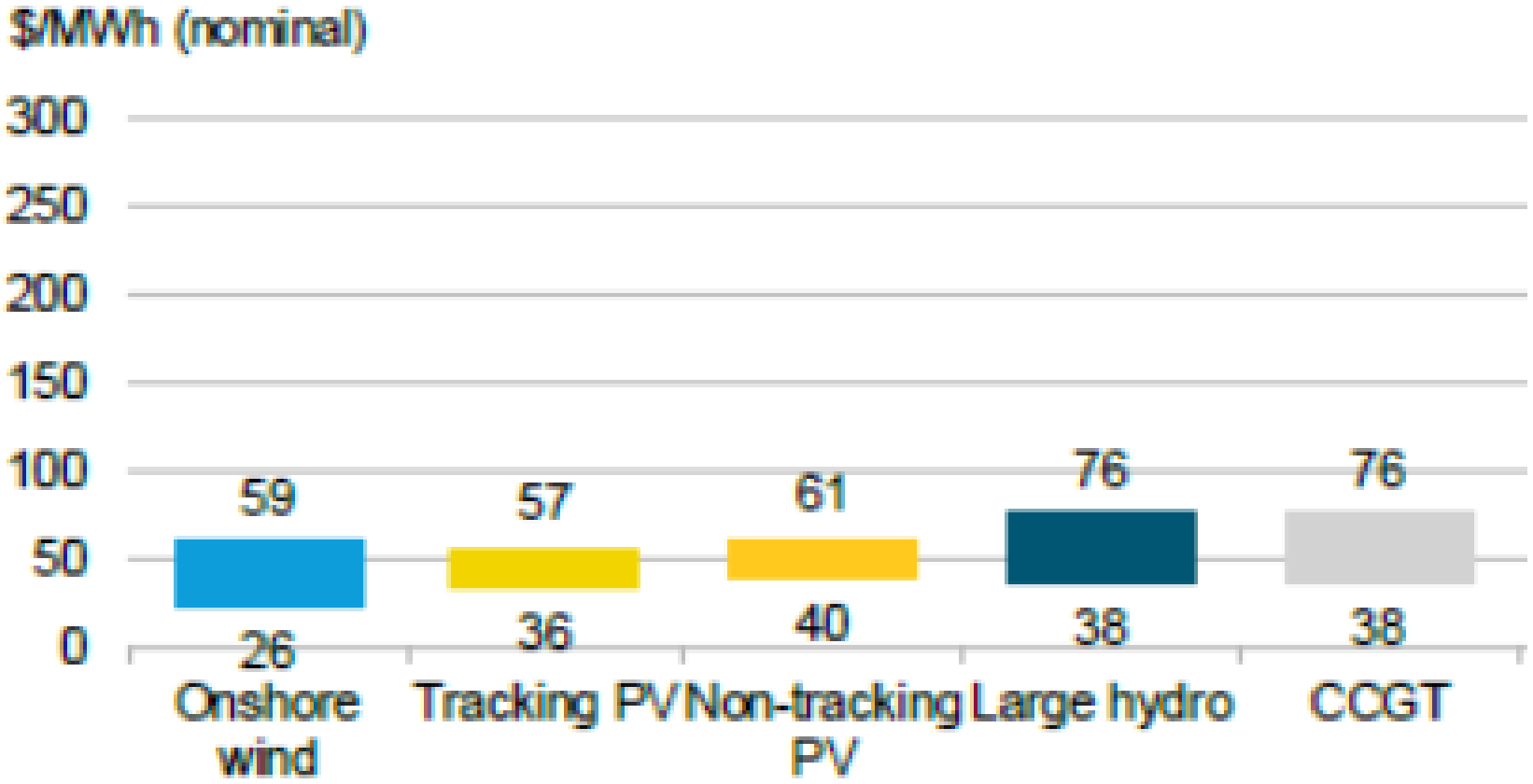


Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this current analysis. These additional factors, among others, could include:
capacity value vs. energy value;
network upgrades, transmission, congestion or other integration-related costs;
significant permitting or other development costs, unless otherwise noted;
and costs of complying with various environmental regulations (e.g., carbon emissions offsets or emissions control systems).

This analysis also does not address potential social and environmental externalities, including, for example, the social costs and rate consequences for those who cannot afford distributed generation solutions, as well as the long-term residual and societal consequences of various conventional generation technologies that are difficult to measure (e.g., nuclear waste disposal, airborne pollutants, greenhouse gases, etc.)

https://www.lazard.com/perspective/lcoe2019

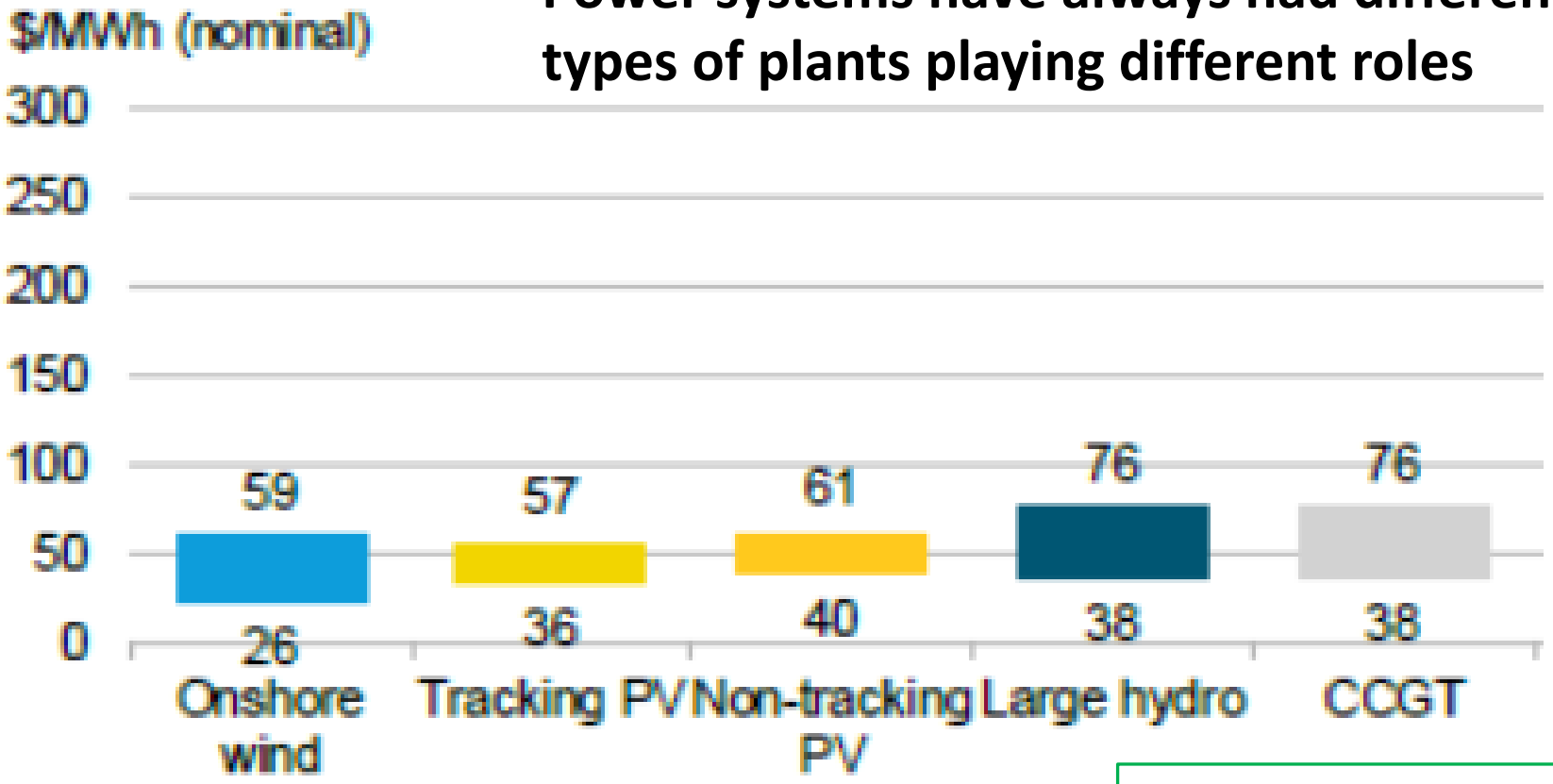
BNEF COMPARISON OF LCOE (2020):



http://www.bcse.org/factbook/#

BNEF COMPARISON OF LCOE (2020):
APPLES TO APPLES? OR APPLES TO ORANGES?

Power systems have always had different types of plants playing different roles

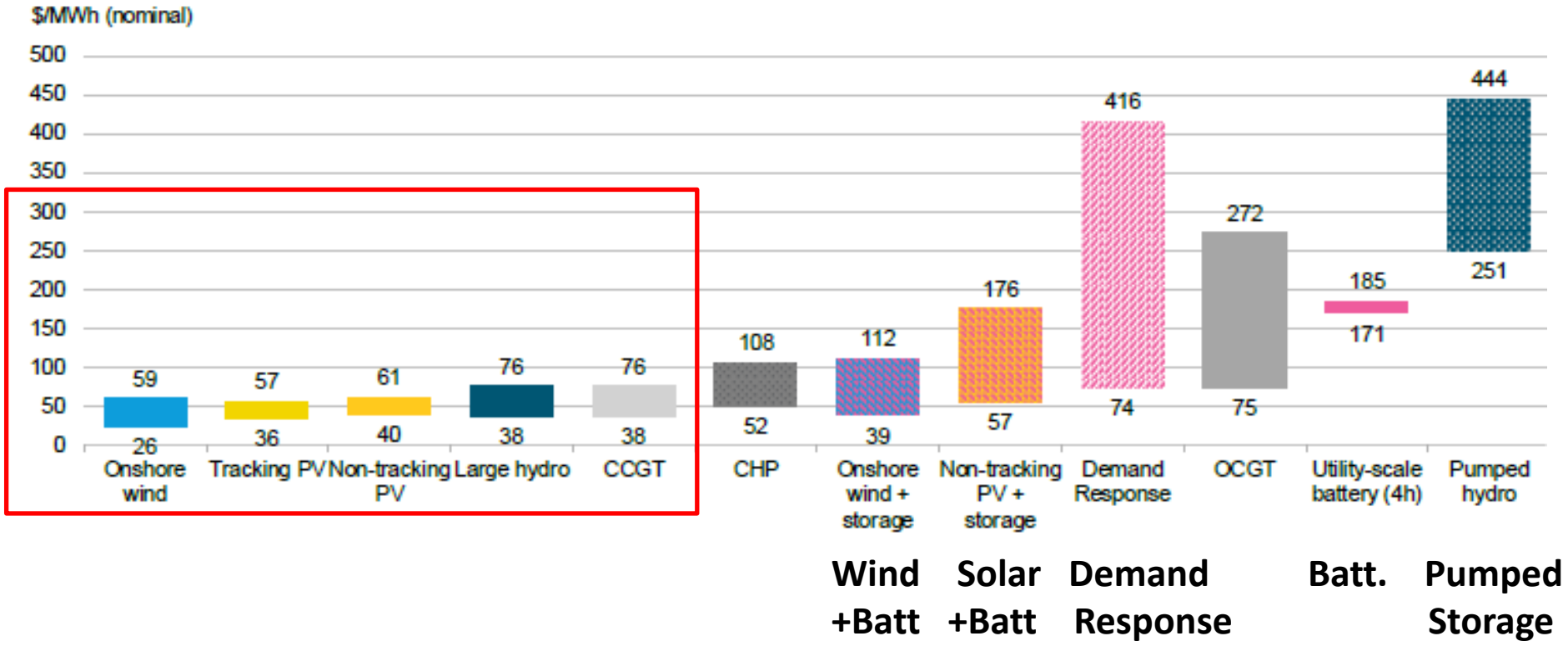


Nuclear,
Coal , Coal with CCS
Gas Peaker, Gas with CCS,
Rooftop PV

http://www.bcse.org/factbook/#

BNEF COMPARISON OF LCOE: GENERATION OPTIONS AND INTEGRATION OPTIONS

Cost of adding [just] 4 hours of battery storage, pumped hydro storage, and demand response is 2x, 3x, or up to 8x the LCOE of wind or solar



http://www.bcse.org/factbook/#

SPREADING OUR CHIPS

UCS REPORT CITES VALUE OF EXISTING NUCLEAR PLANTS (2018)

- **Without policies to replace retired nuclear power generation with low-carbon energy technologies, utilities could turn to natural gas and coal to fill the gap**
  - could result in a *4 to 6 percent* increase in US power sector emissions.

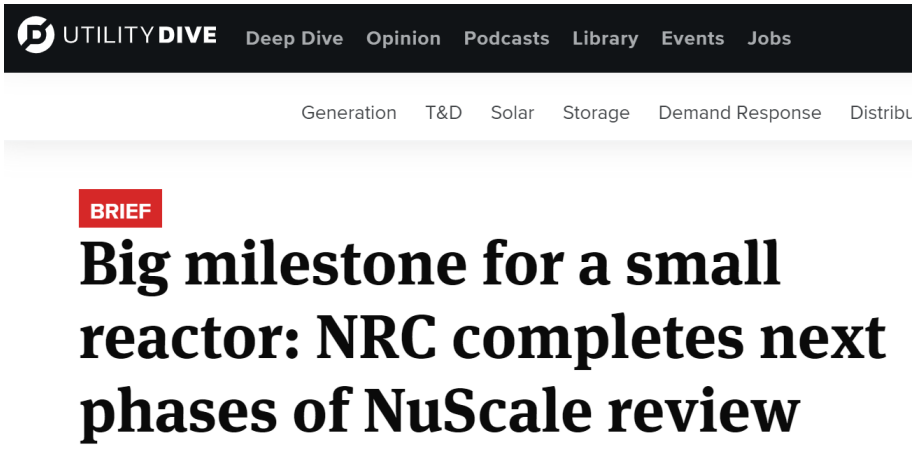

Union of Concerned Scientists

EXECUTIVE SUMMARY

The Nuclear Power Dilemma

Declining Profits, Plant Closures, and the Threat of Rising Carbon Emissions

SMALL MODULAR REACTORS HOLD PROMISE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BRIEF

Big milestone for a small reactor: NRC completes next phases of NuScale review

https://www.ucsusa.org/sites/default/files/attach/2018/11/Nuclear-Power-Dilemma-executive-summary.pdf

SPREADING OUR CHIPS

CARBON CAPTURE AND STORAGE WORKS, AND COSTS WILL DECREASE WITH INNOVATION AND SCALE

Vox

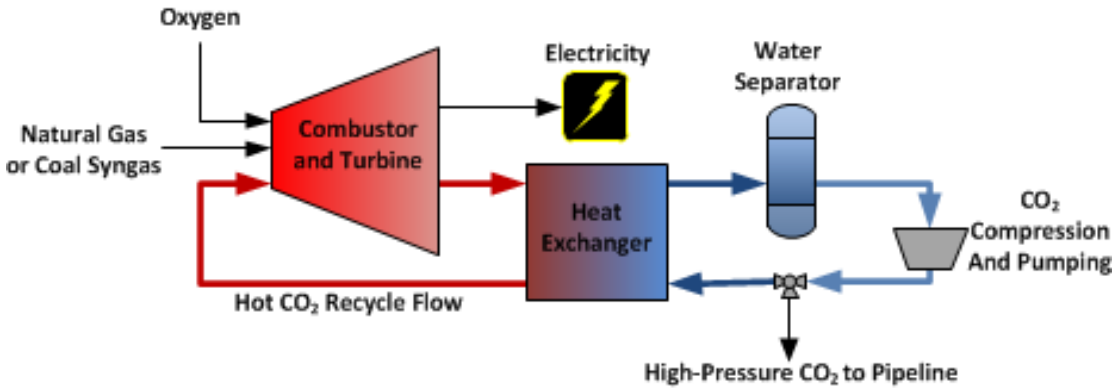
RECODE EXPLAINERS THE HIGHLIGHT FUTURE PERFECT THE GOODS POLITICS & POLICY MORE

That natural gas power plant with no carbon emissions or air pollution? It works.

The carbon-capture game is about to change.

By David Roberts | @drvox | david@vox.com | Jun 1, 2018, 9:40am EDT

NETPOWER



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